Numerical modeling

that predicts, optimizes and innovates

Compressible Flow Modeling Occurring in a Depressurization Process

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COMSOL CONFERENCE
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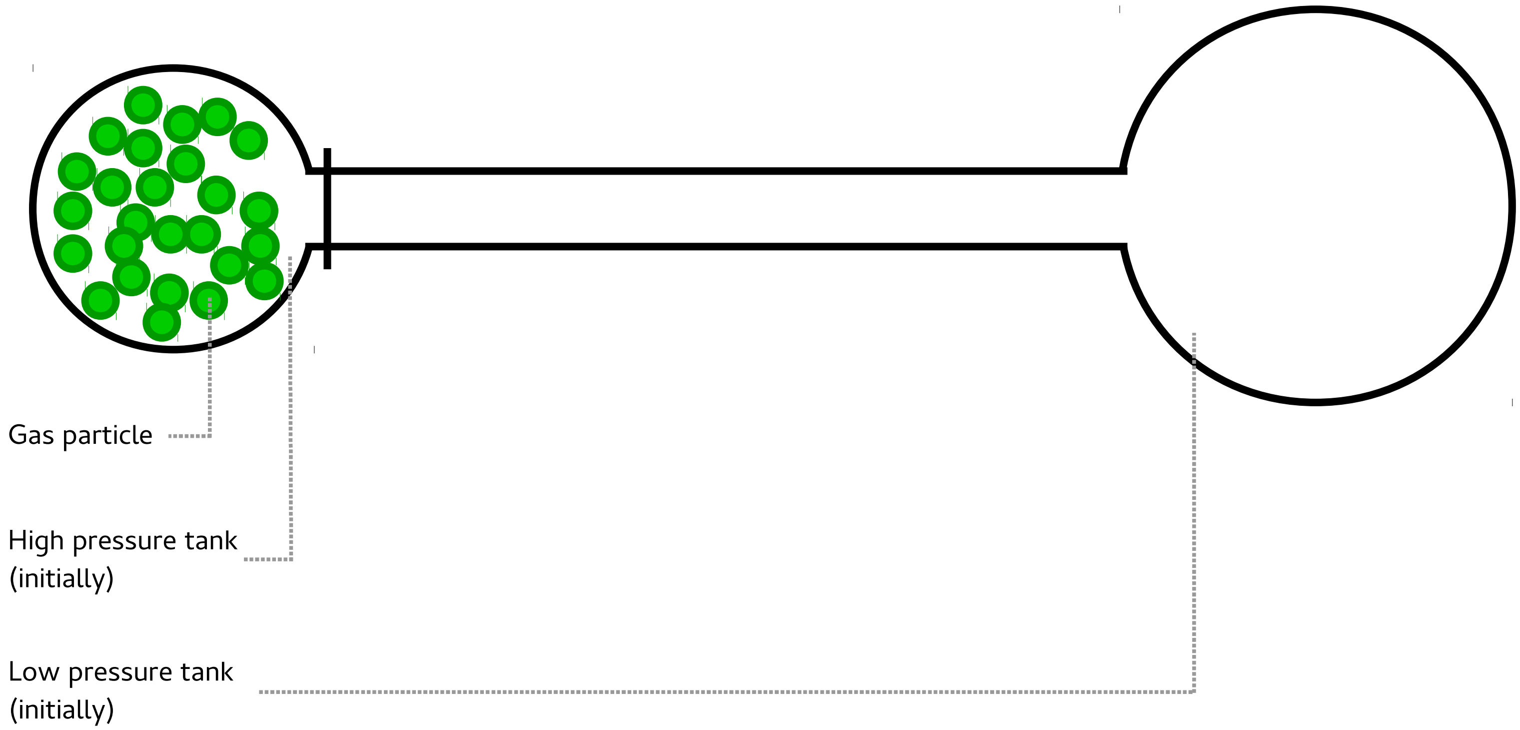

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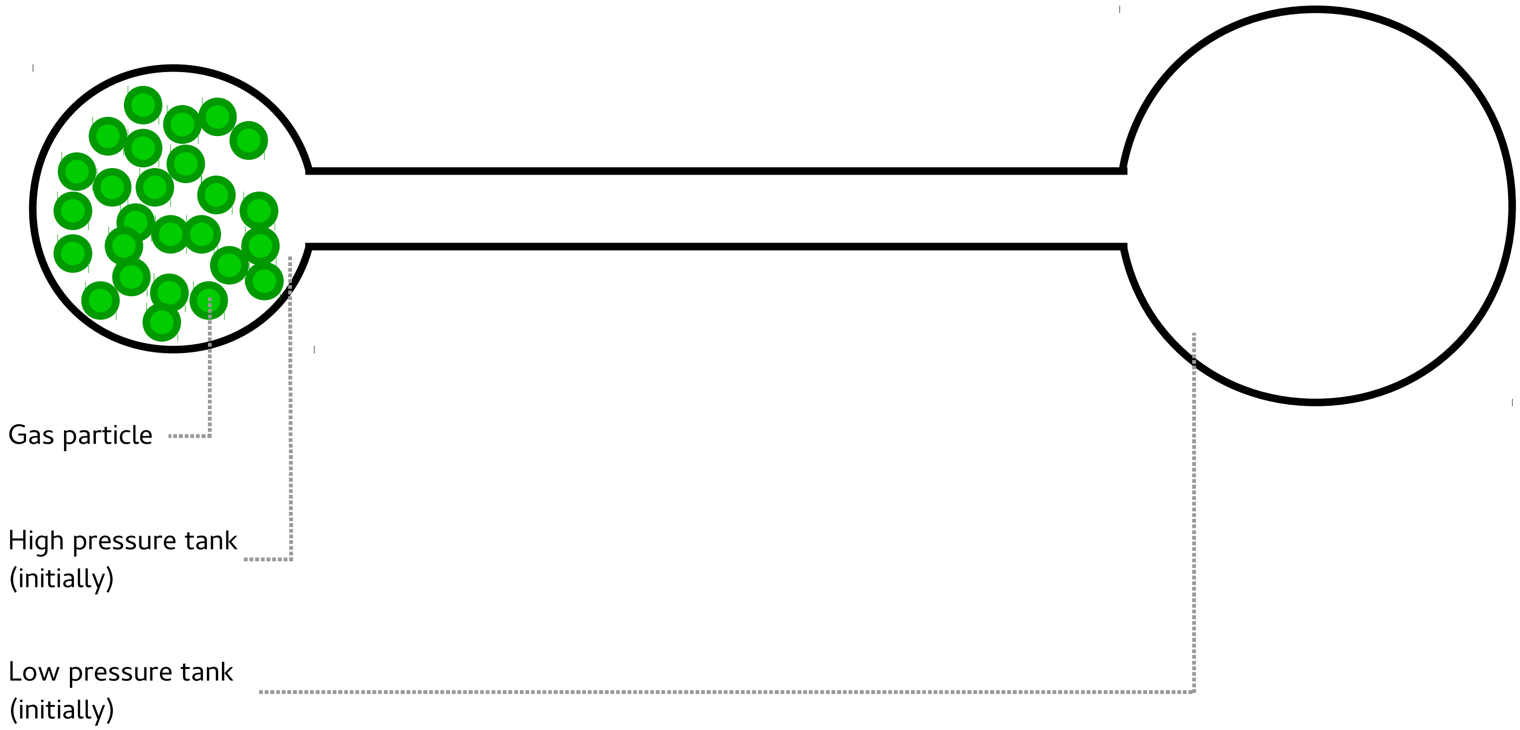

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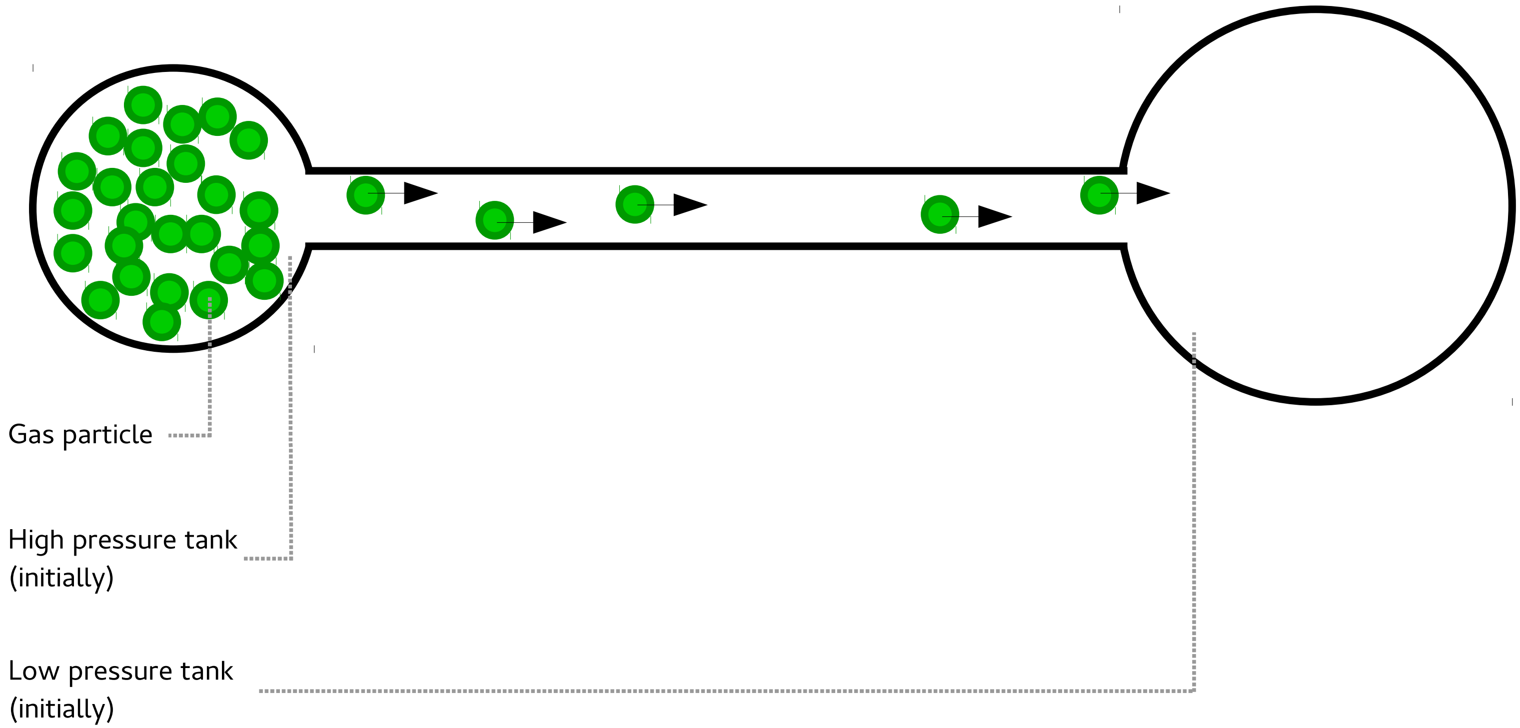

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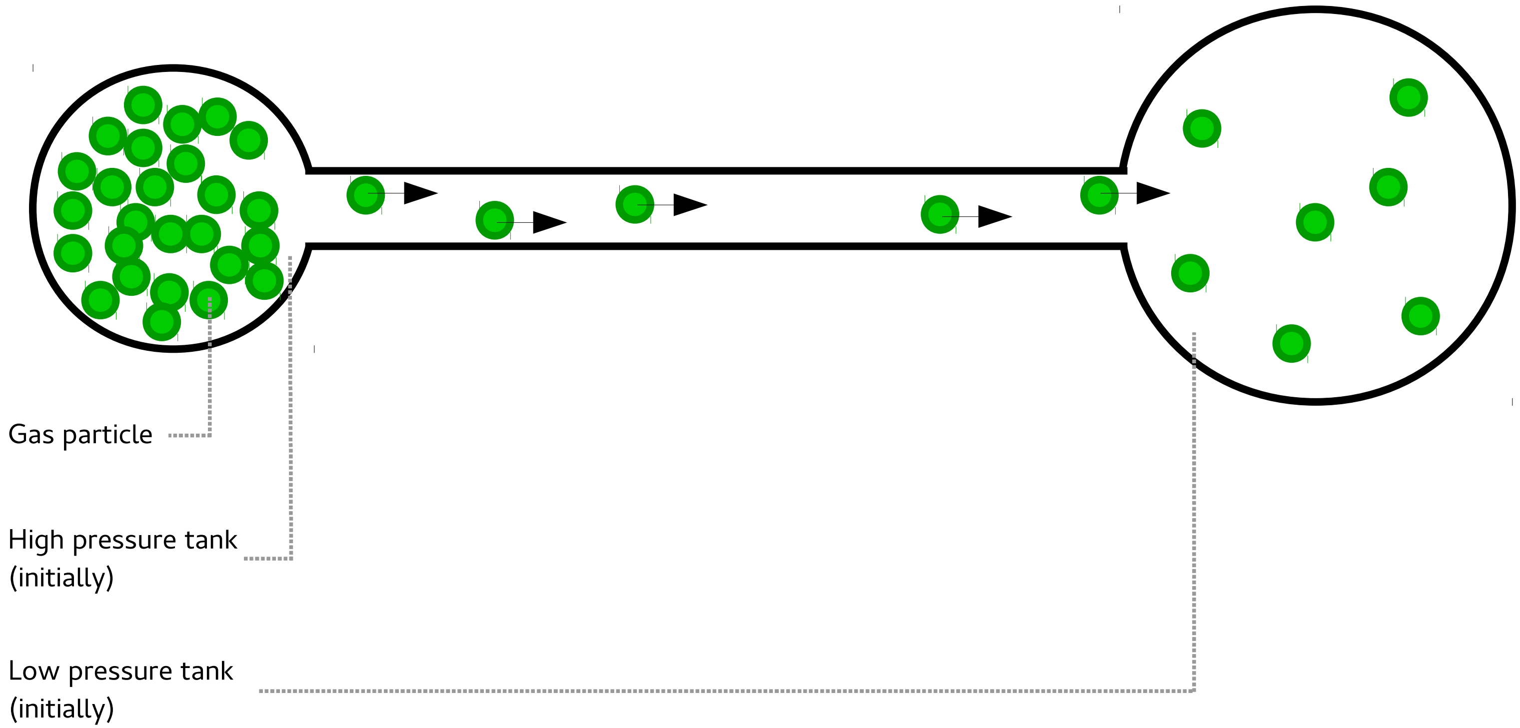

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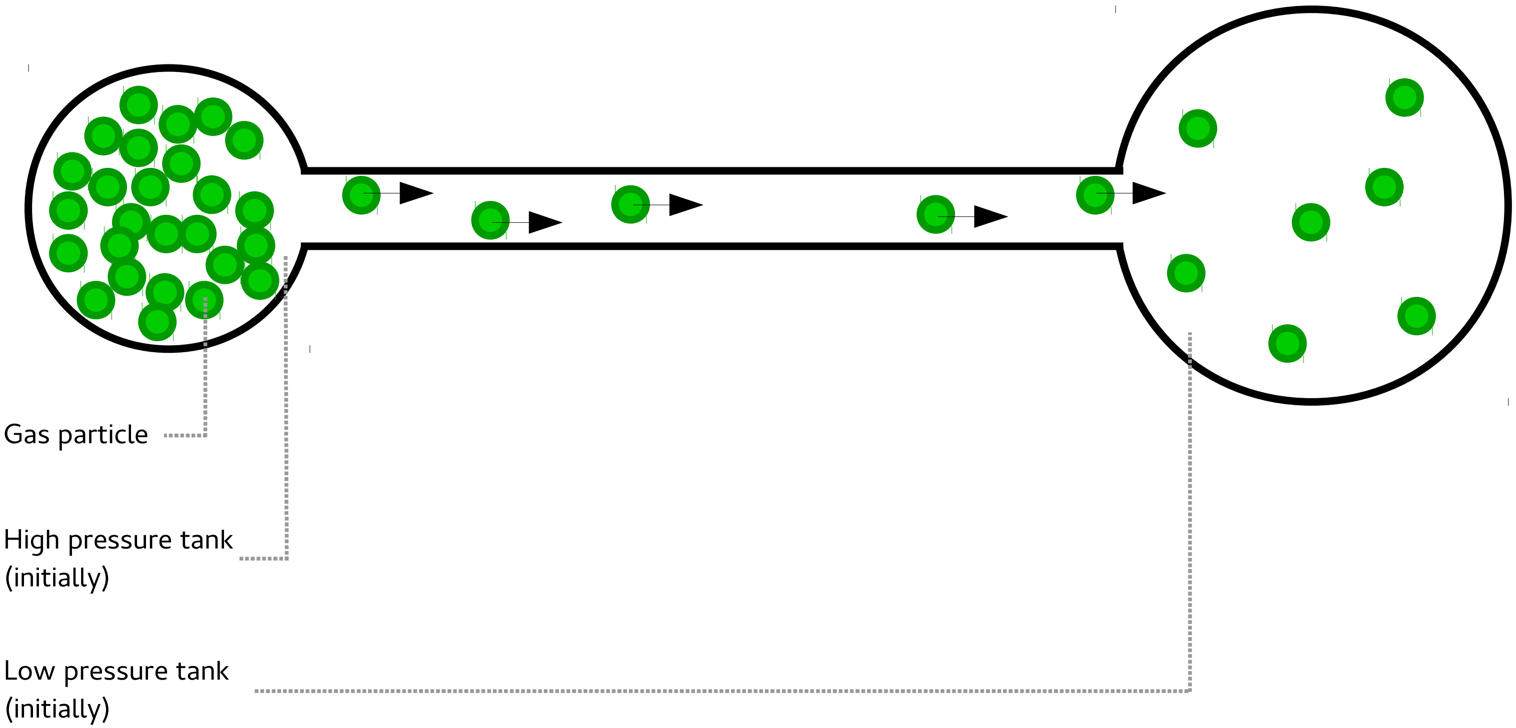

Model the flow to:

- *Study the sensitivity to the dimensions of the system;*
- *Understand the behavior of the gas flow, the time to reach the equilibrium;*
- *Coupling with others physics: e.g. chemistry, ... etc*

The Flow Study and its Issues

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$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0$$

$$\rho \frac{\partial u}{\partial t} + \rho u \cdot \nabla u + \nabla p = \eta \Delta u$$

Navier-Stokes Equations (Mass and momentum balances)

$$\rho c_p \left(\frac{\partial T}{\partial t} + u \nabla T\right) = \nabla \cdot (\lambda \nabla T) + \frac{\partial p}{\partial t} + u \nabla p$$

Energy balance

$$pM = \rho R T$$

Constitutive law

Precise description of the movement!

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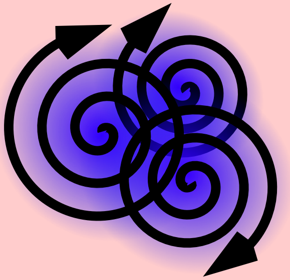

Turbulent flow : **difficult to capture numerically**

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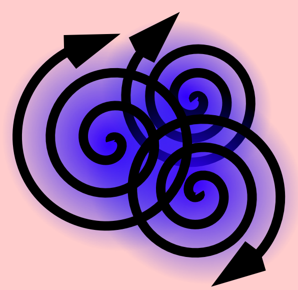

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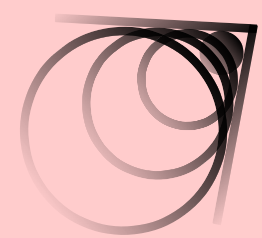

Shockwaves appearing at the sound speed : **it breaks the continuity hypothesis!**

Overview

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Model derived from an existing 1D approach

A Simplified Model for Real Gas Expansion Between Two Reservoirs Connected by a Thin Tube, S. Charton, V.Blet et J. P. Corriou, 1995

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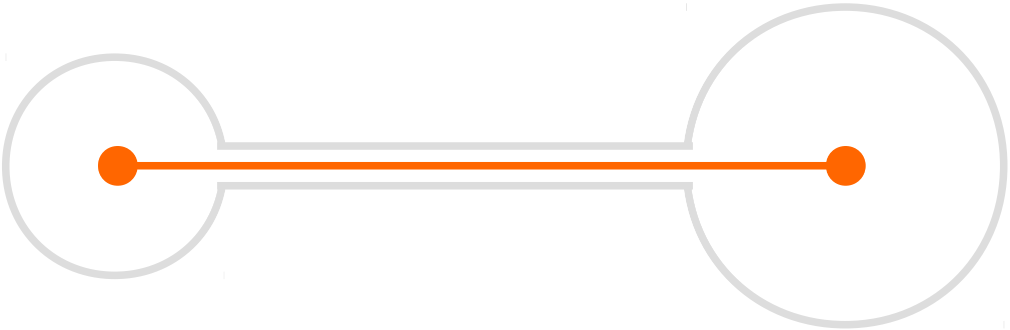

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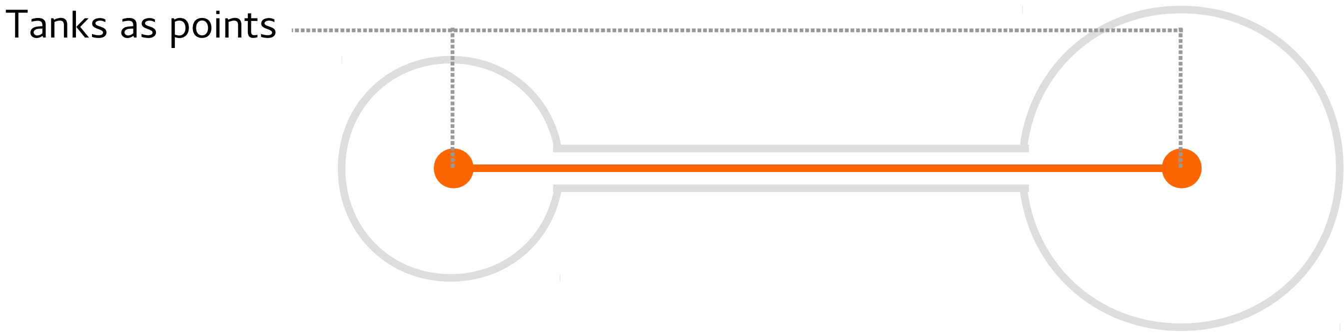

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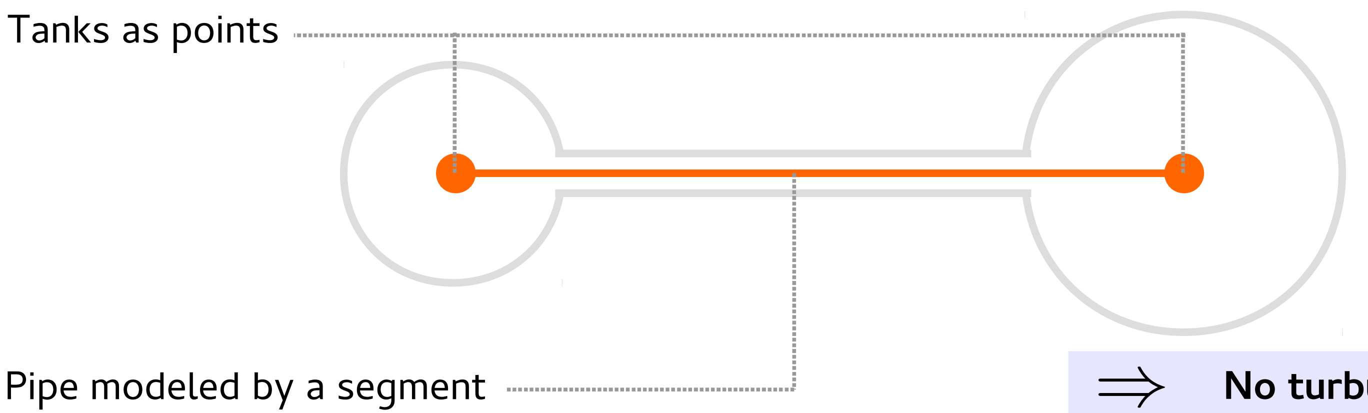

⇒ **No turbulences to handle**

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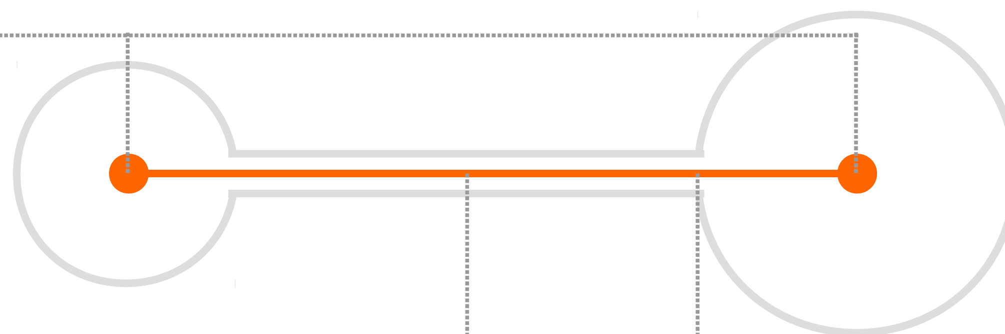

Pipe modeled by a segment

Location of the discontinuity given by a theoretical development

$\Rightarrow$ **No turbulences to handle**

$\Rightarrow$ **Possibility to introduce the discontinuity**

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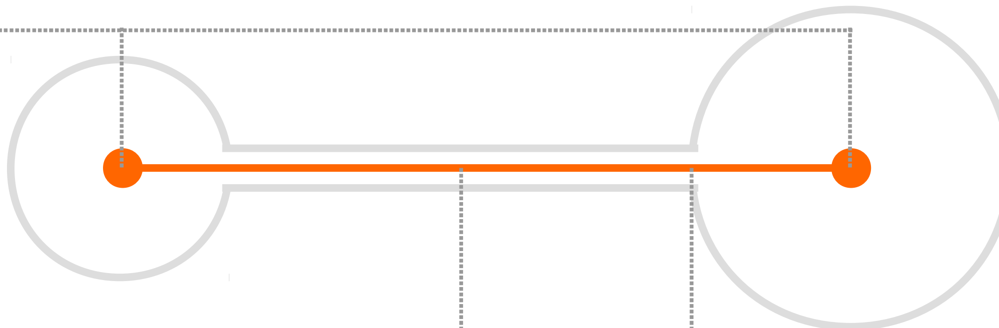

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How to model the **gas flow**, **the tanks** and the **discontinuity** within COMSOL?

Gas Flow Within the Pipe

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COMSOL

ODE and PDE interfaces
or
Pipe Flow Module interfaces

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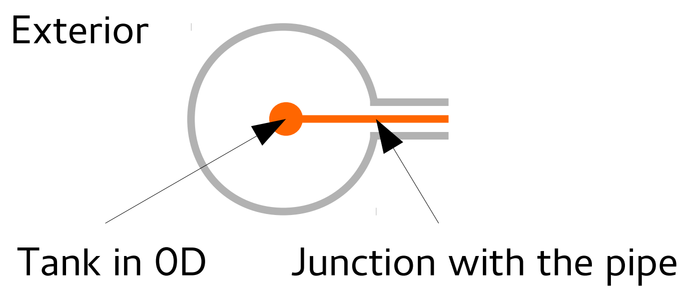

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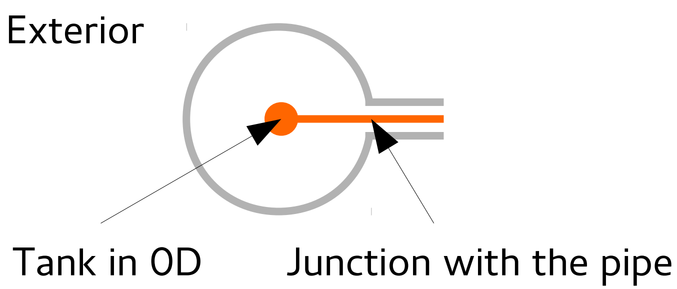

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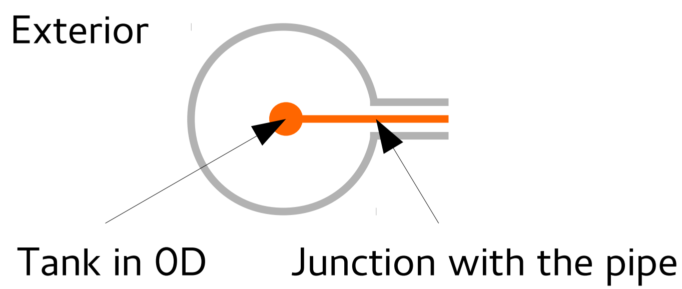

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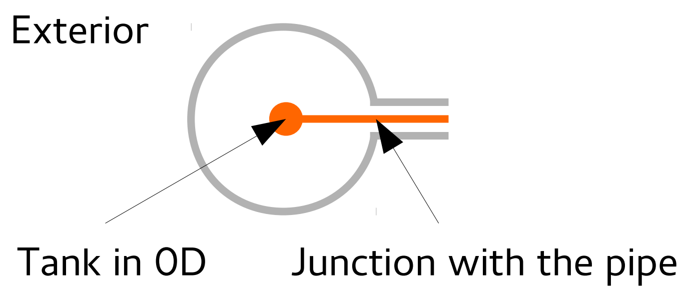

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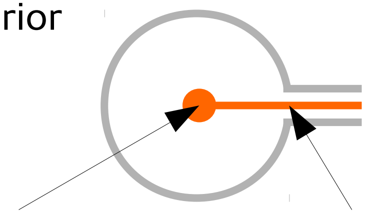

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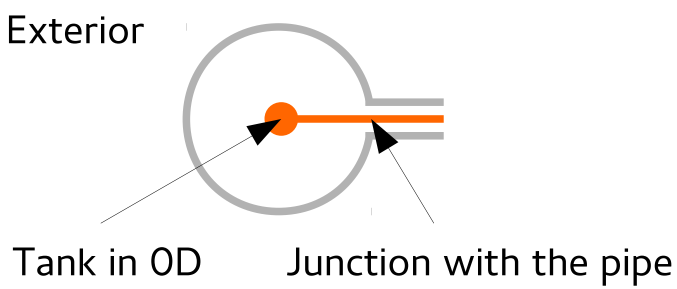

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COMSOL **ODE interface**

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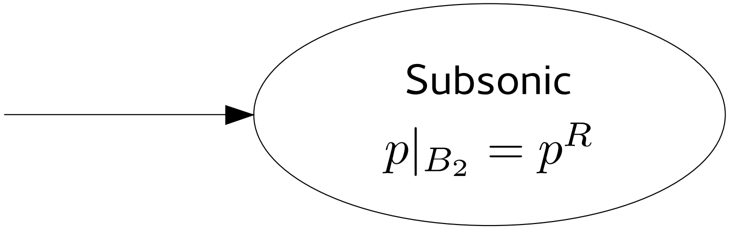

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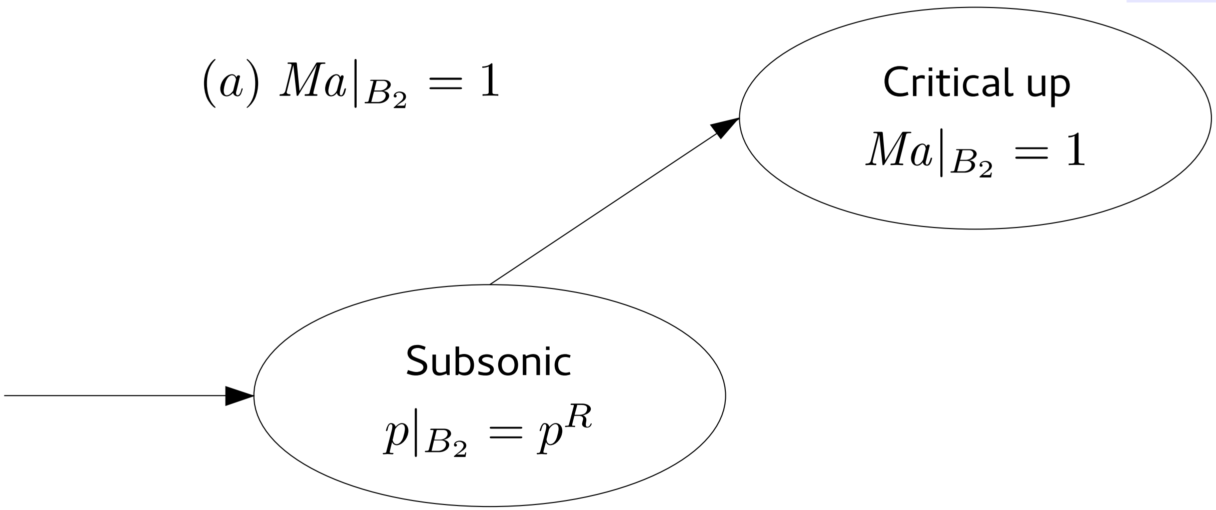
Flow saturated to **Mach 1**
(second law of thermodynamics)



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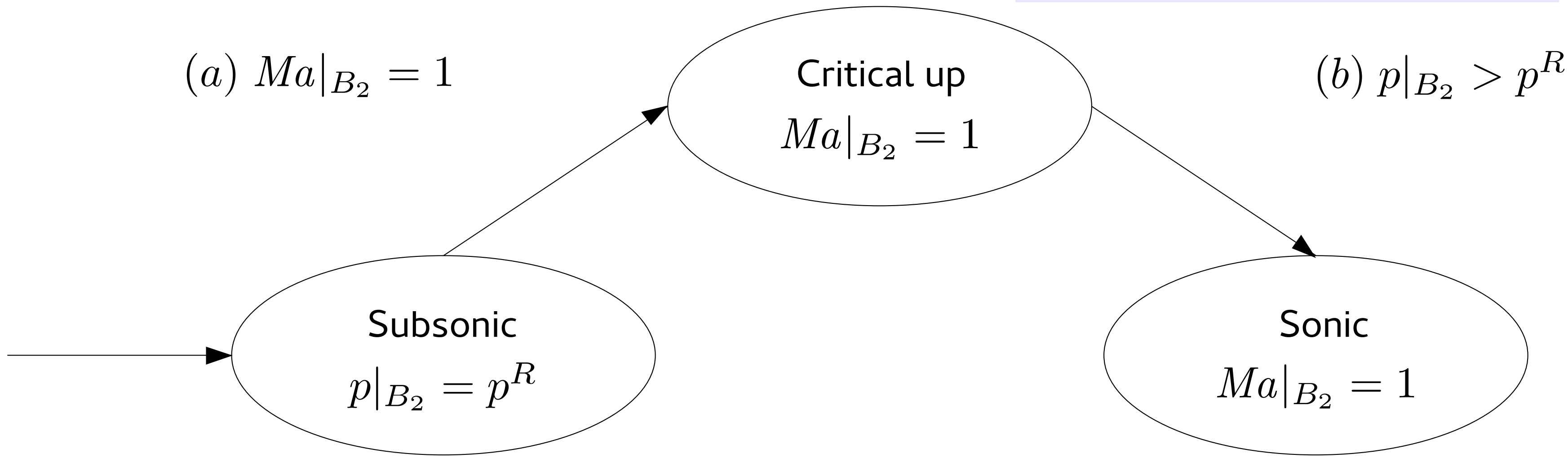

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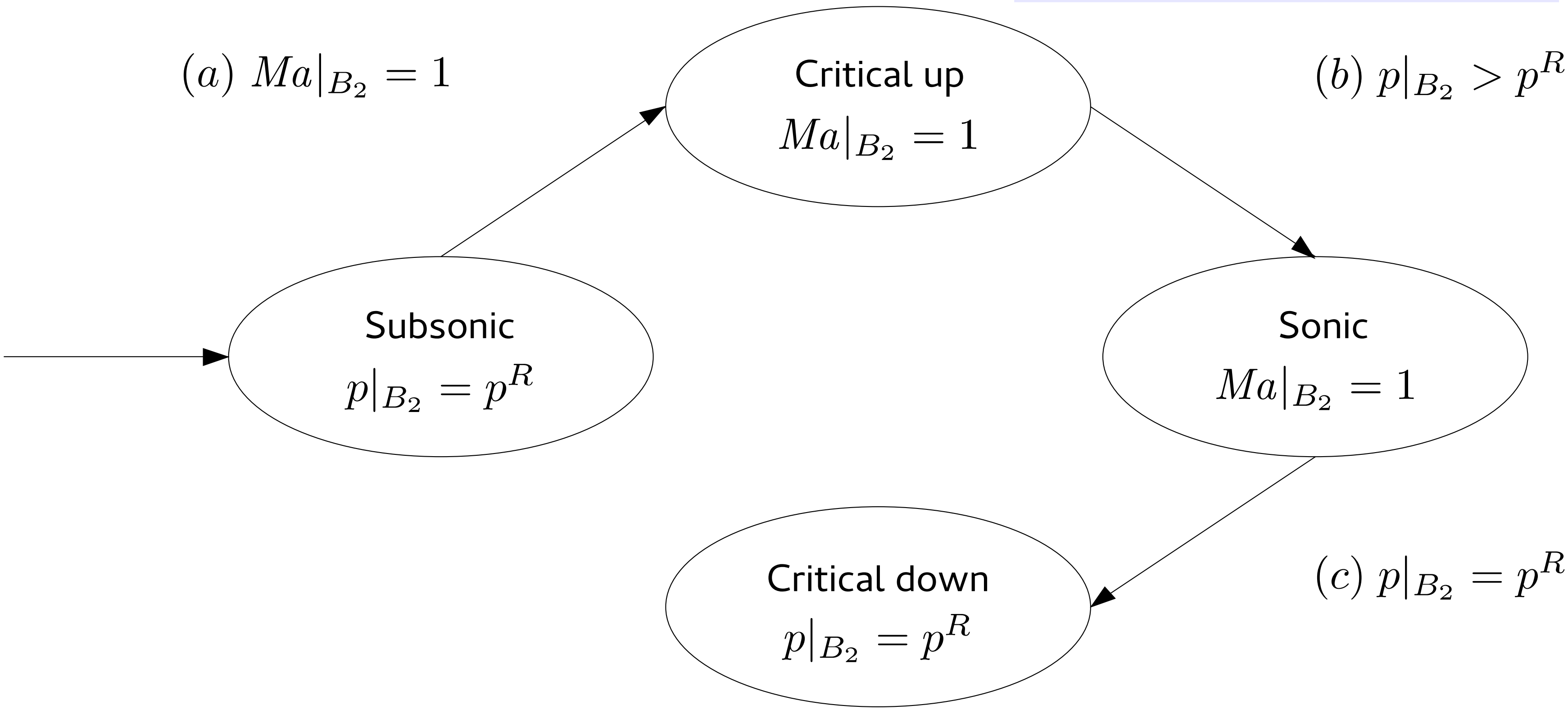

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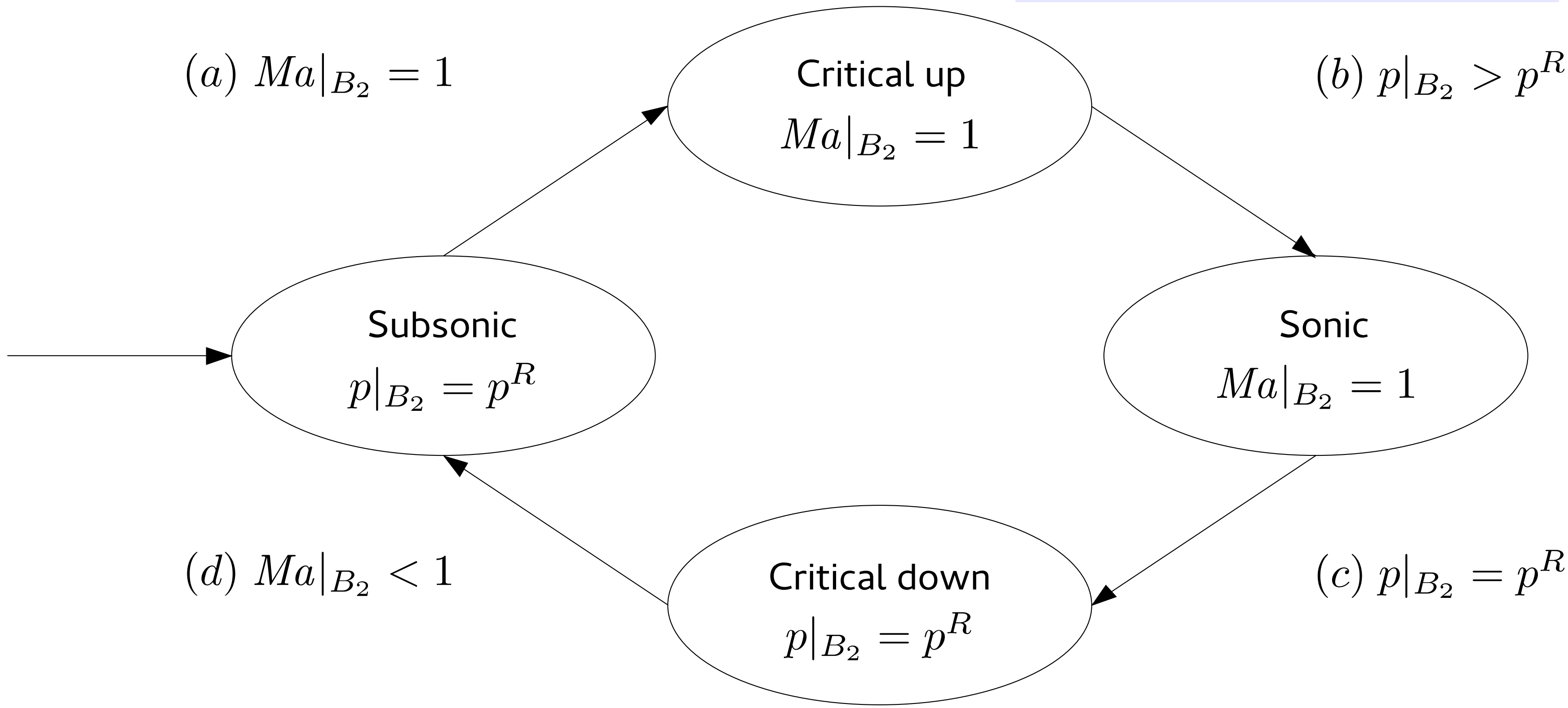

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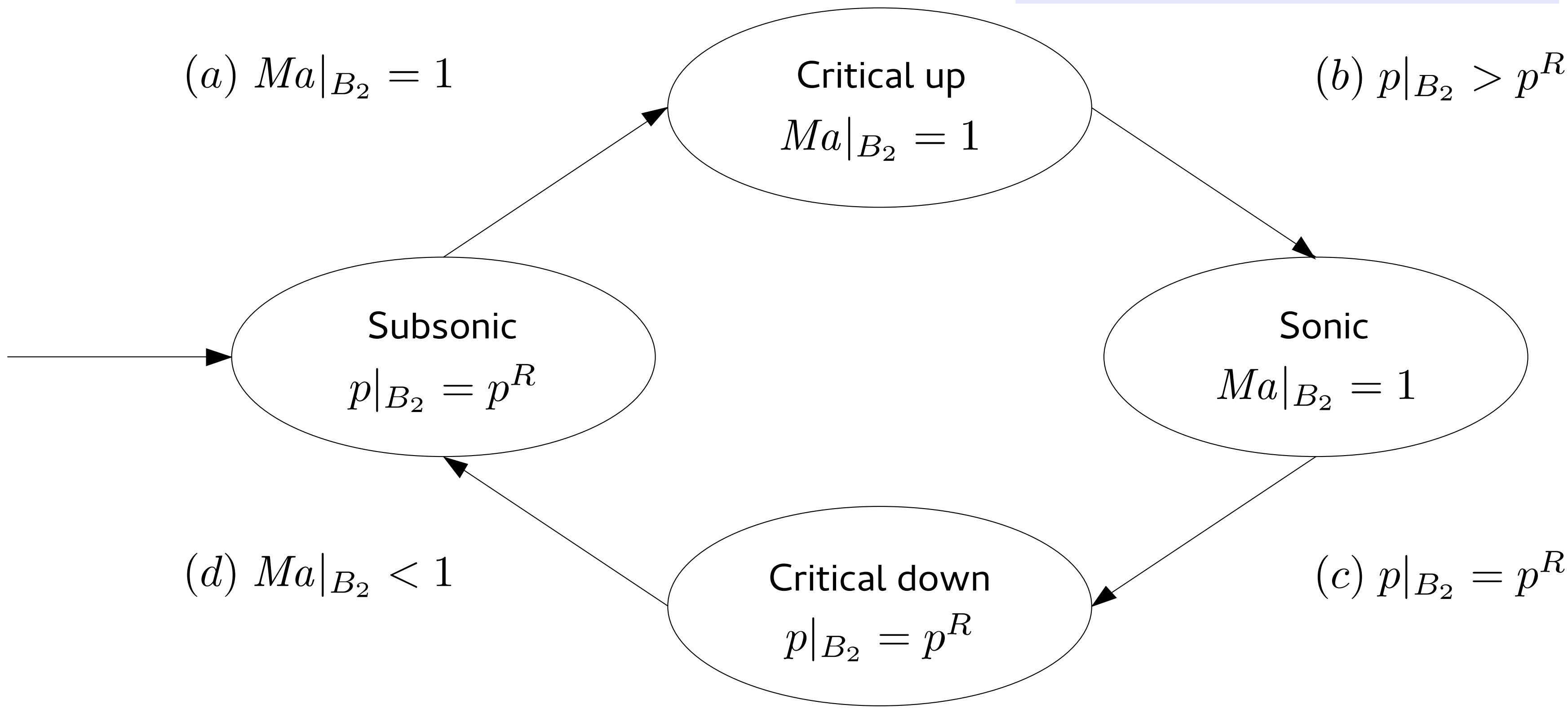

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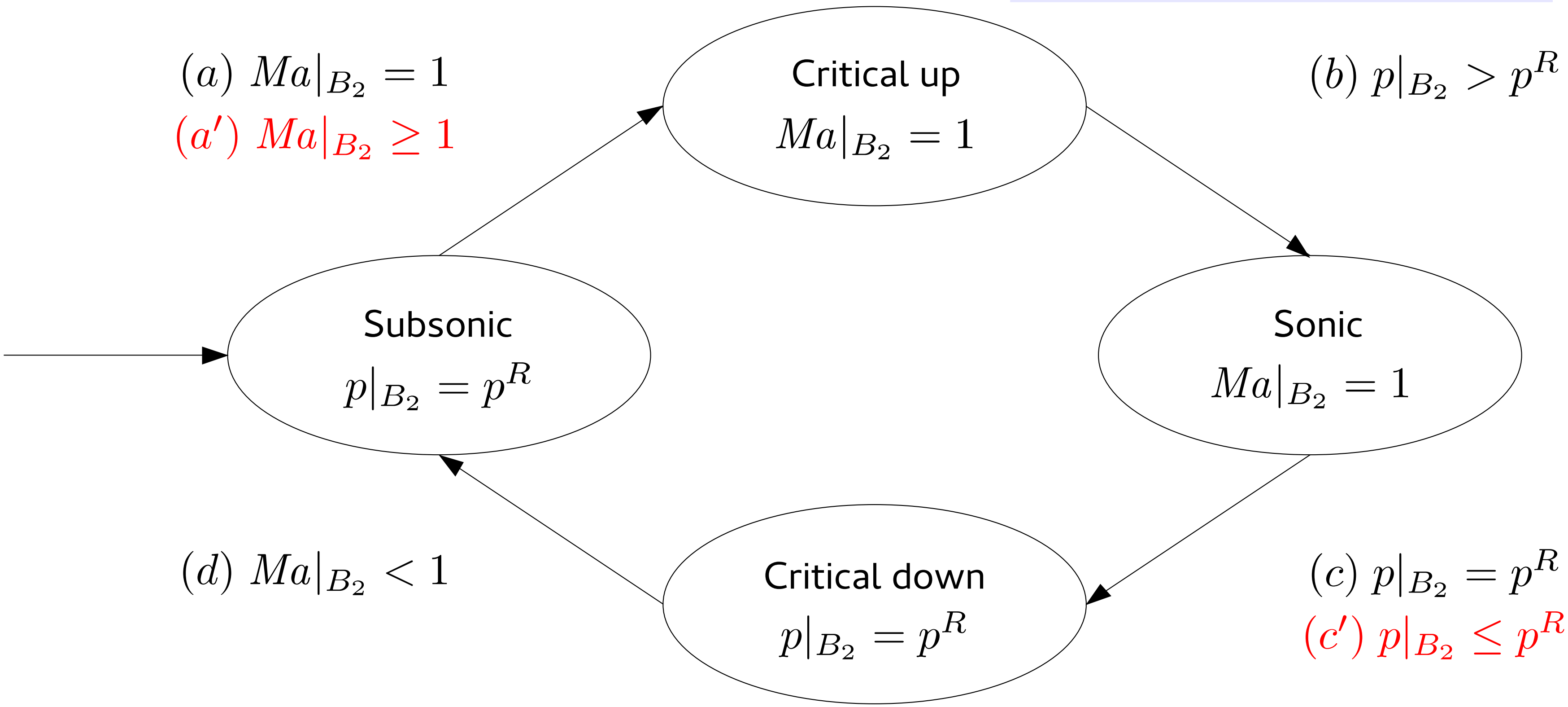

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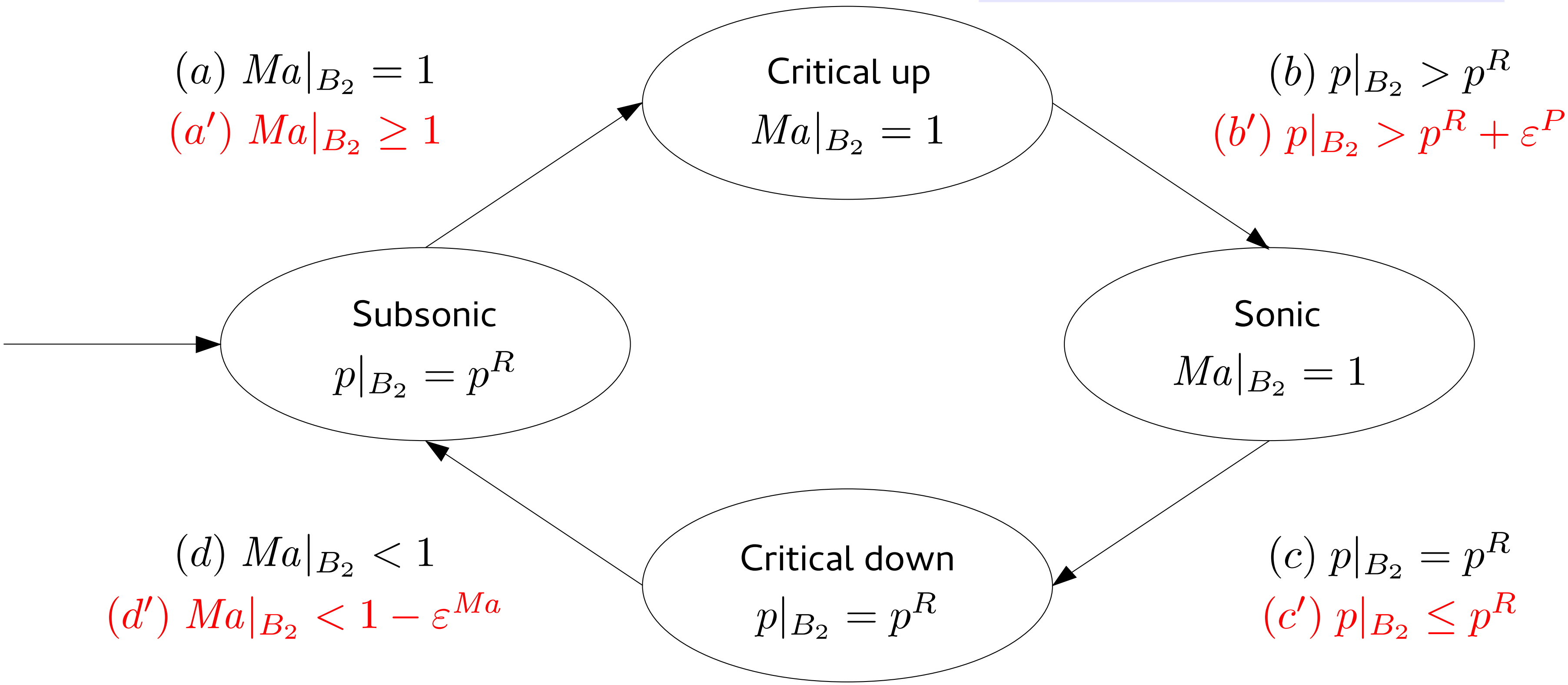

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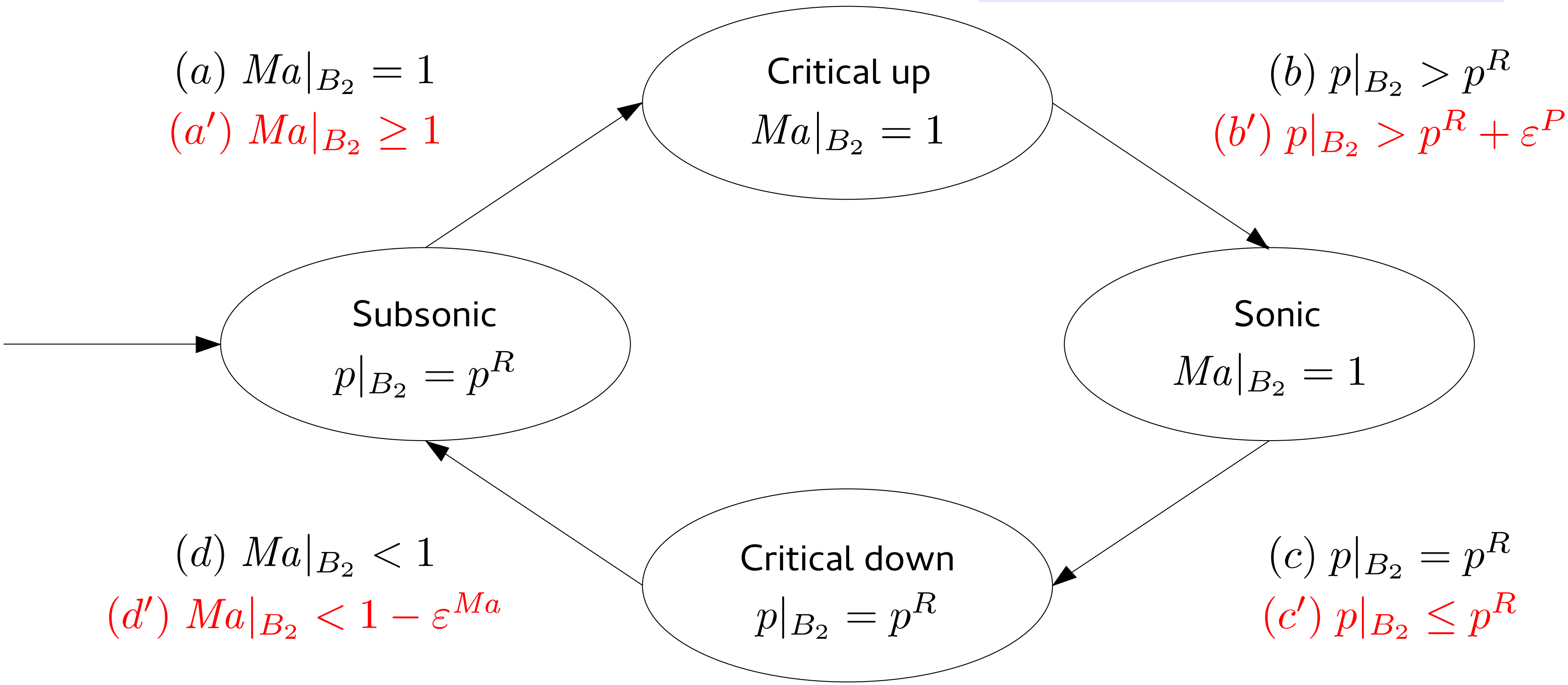

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COMSOL **Events interface**

Numerical Aspects

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Space Discretization

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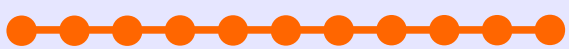
Space Discretization

Study of sensivity to the mesh

$\Downarrow$

At least homogeneous **1000** nodes

Avoid numerical loss of mass during the discharge



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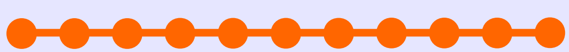

Time Discretization

Numerical Aspects

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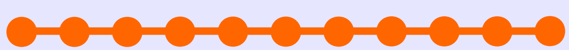

Time Discretization

Speed of sound reached very **quickly**

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Small timestep at the beginning of the simulation (about $\mathbf{10^{-7}s}$)

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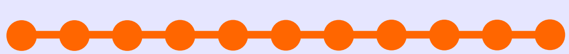

Time Discretization

Speed of sound reached very **quickly**

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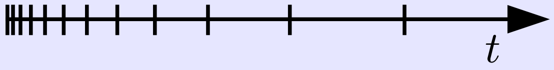
Gas **less agitated** after that: COMSOL chooses well its timestep **automatically**



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Theoretical results exist by neglecting the friction forces

A. Lallemand, Ecoulements monodimensionnels des fluides compressibles, Techniques de l'ingénieur, 2014

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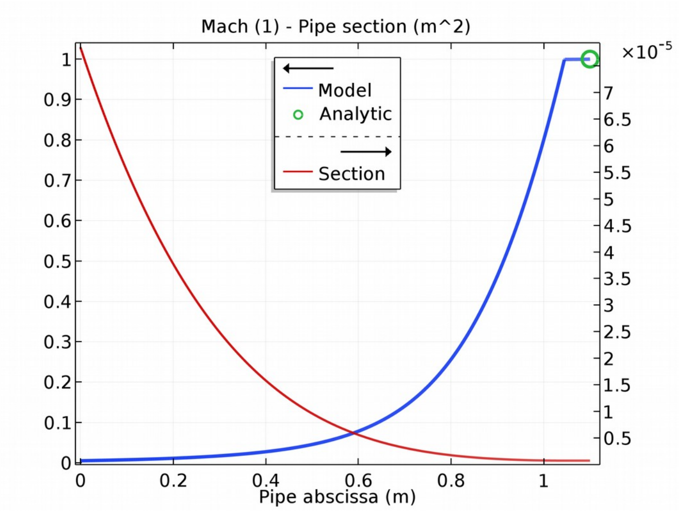

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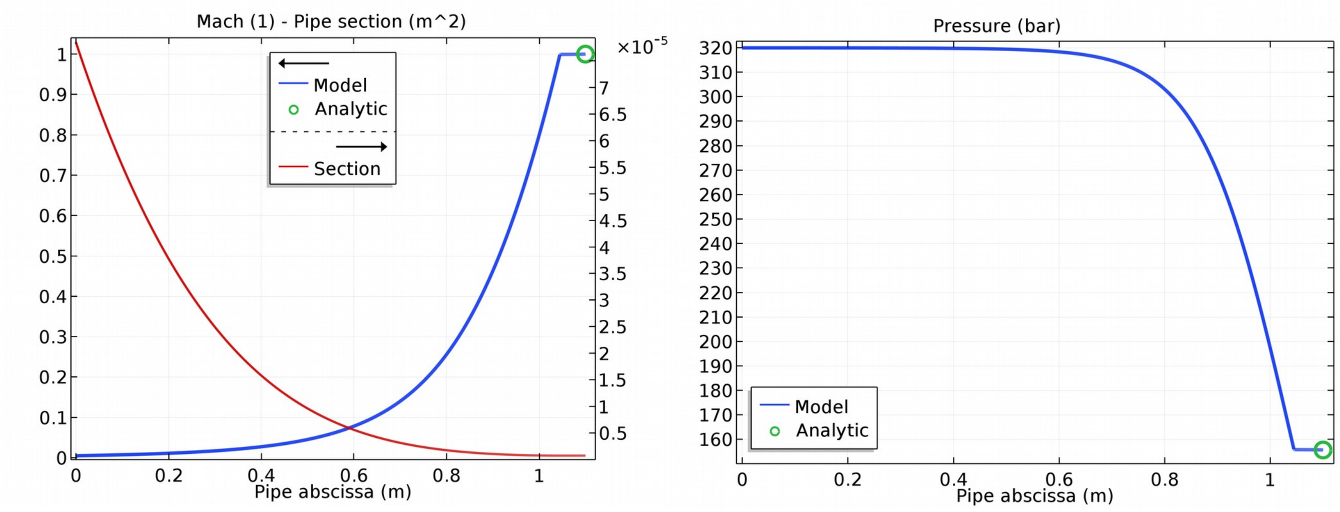

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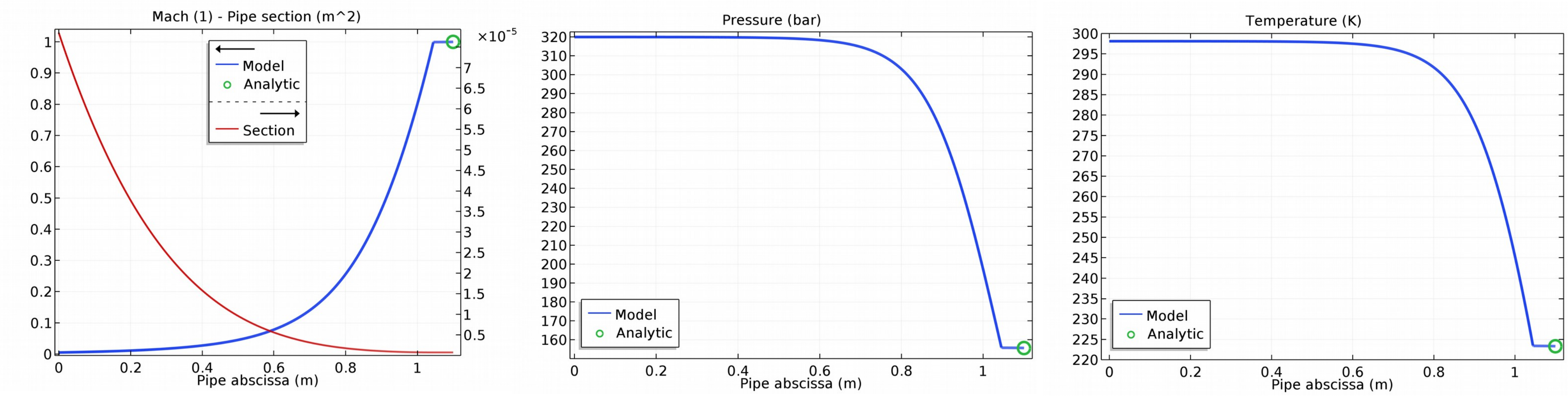

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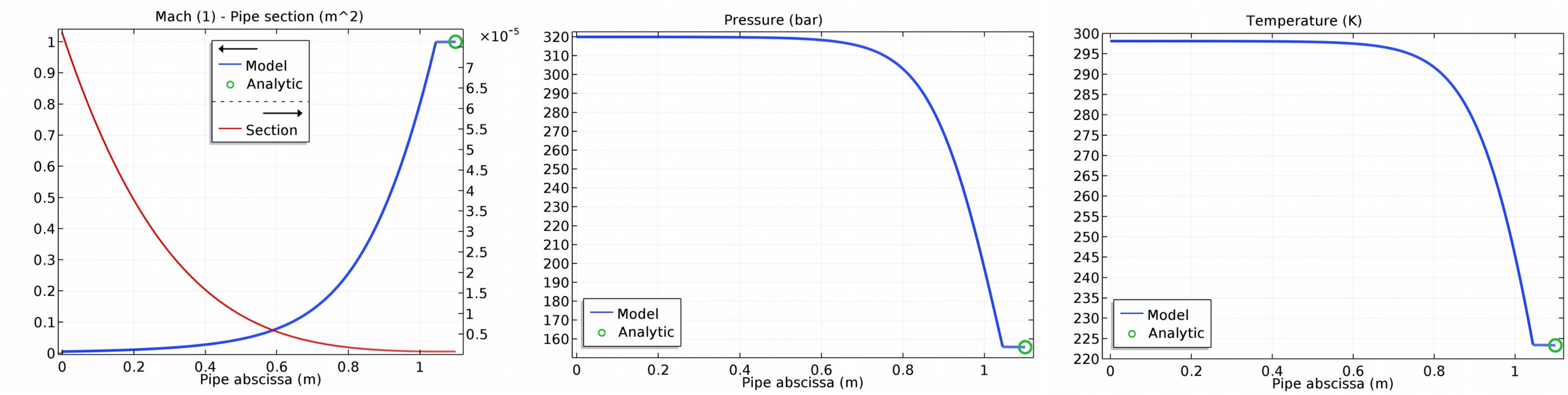

The model respects the physics laws!

First Comparisons with Experiments

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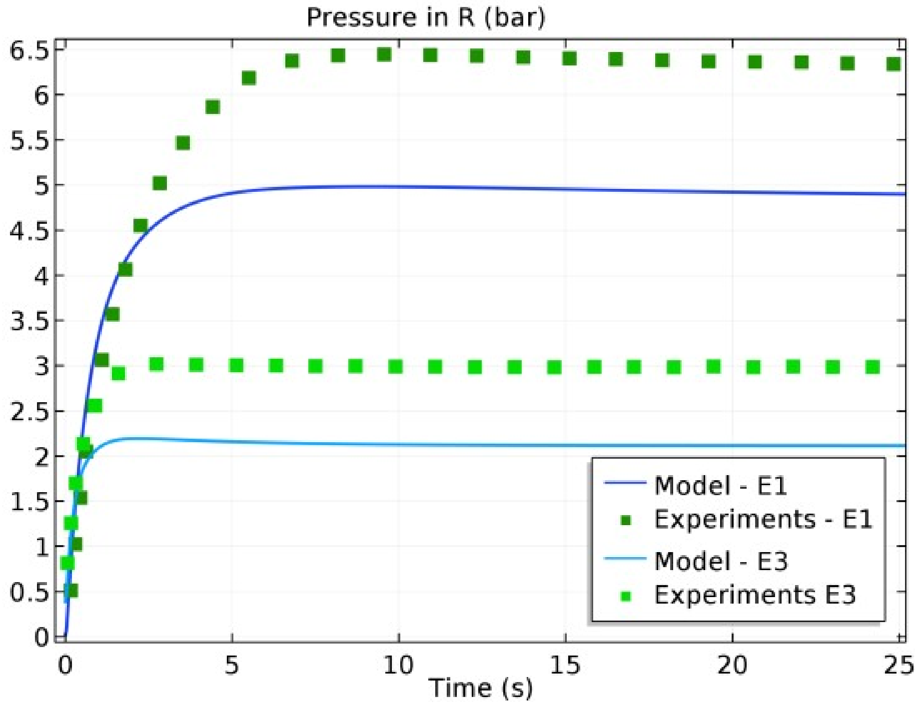

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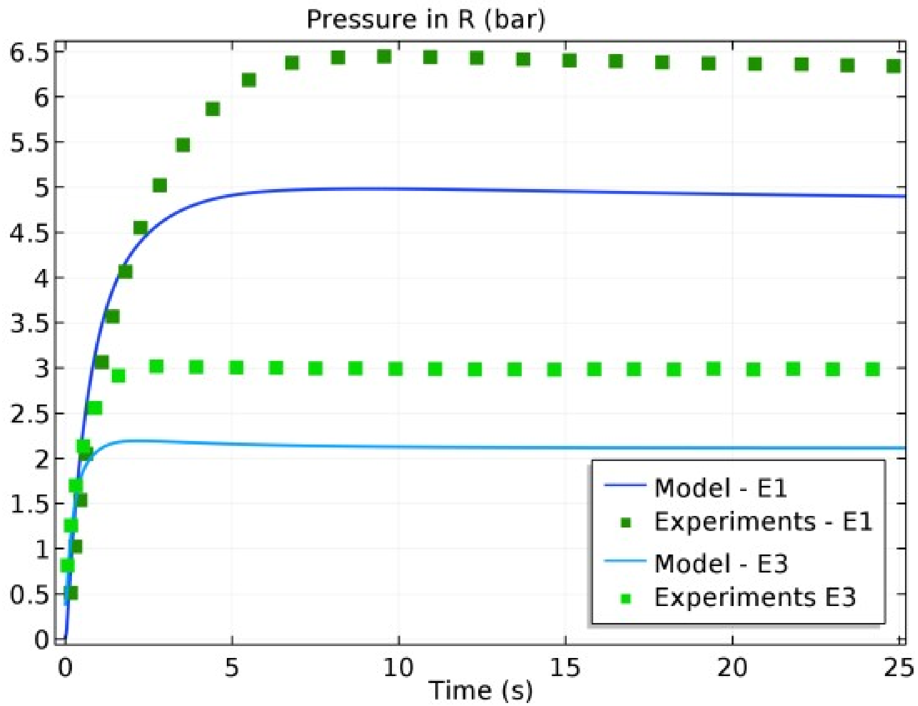

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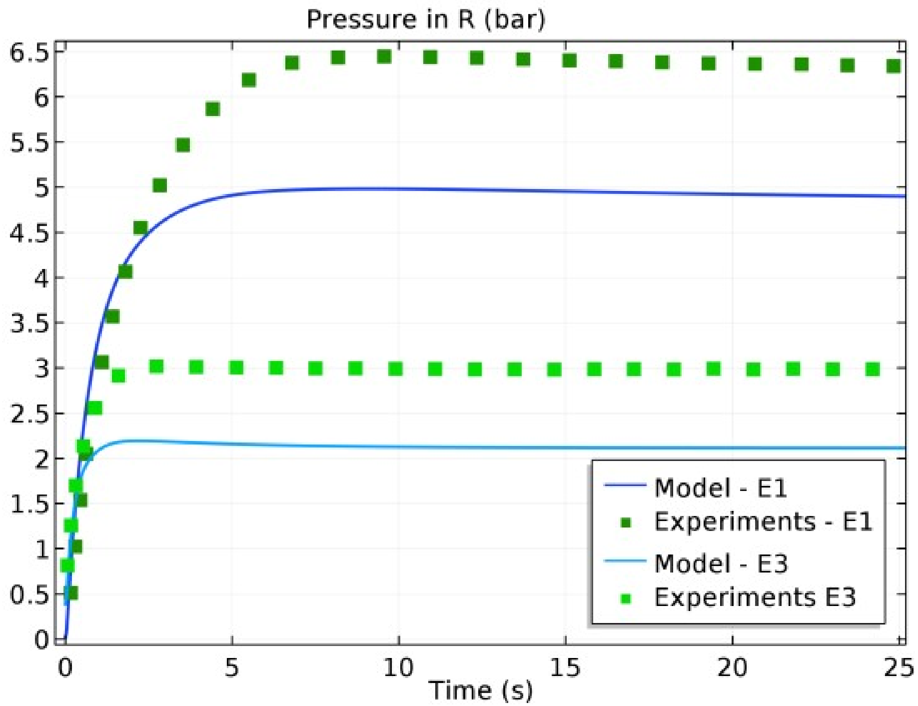

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Tracks to explain that

- Too reductive assumptions (e.g. ideal gas law...)
- The dimensions used to feed the model are not correct
- Some of the experimental results are not accurate enough
- A mix of them all

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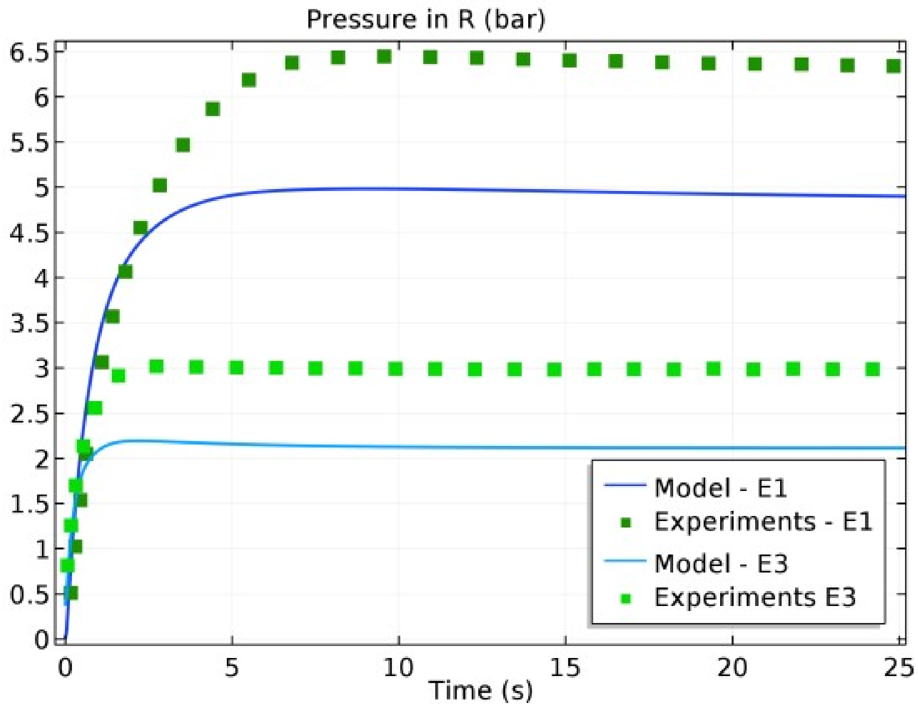

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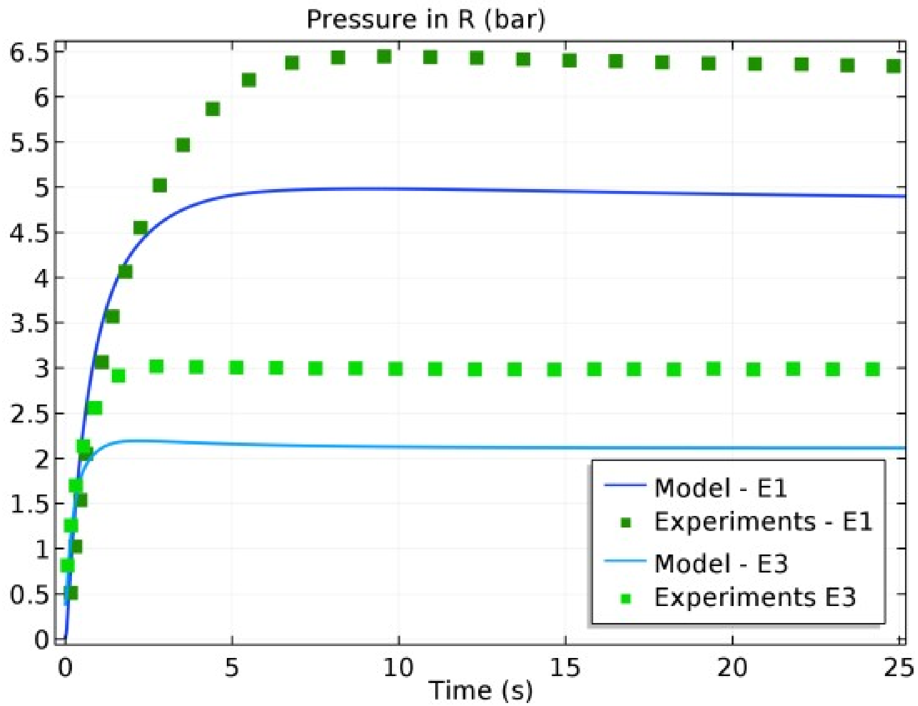

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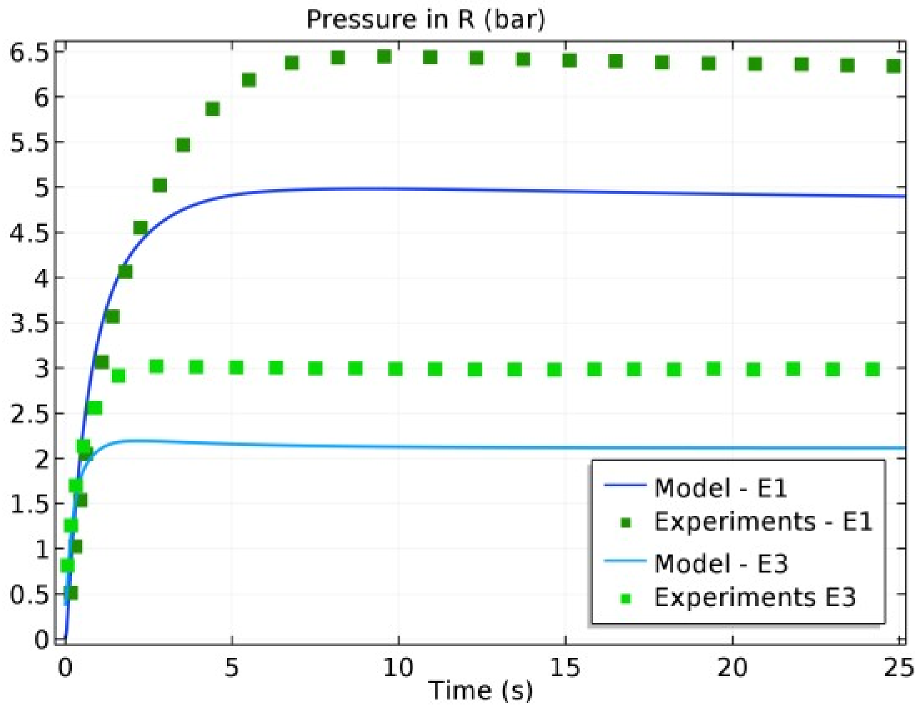

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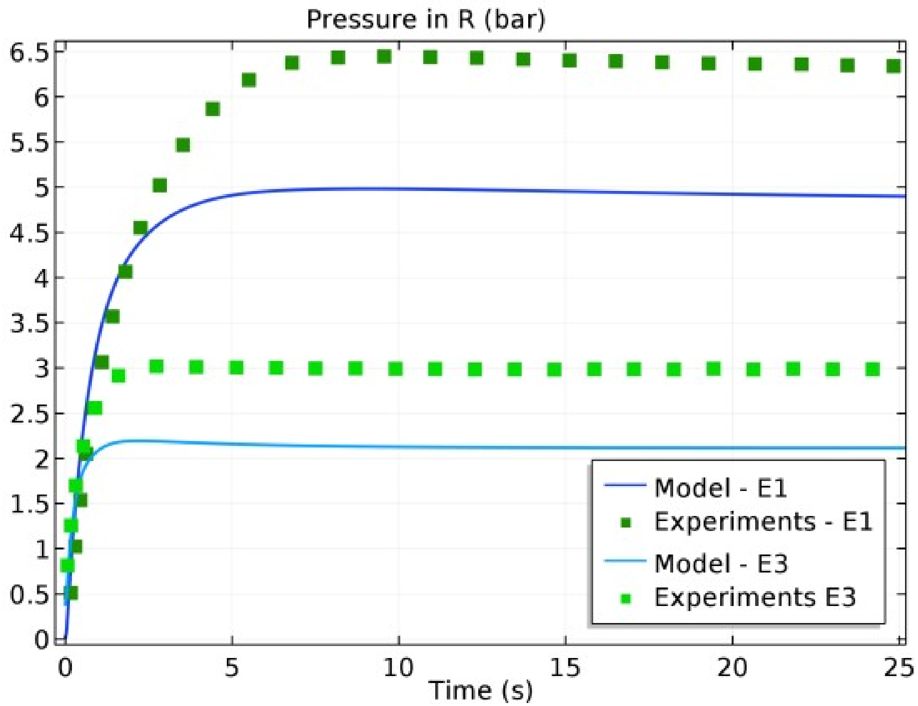

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  ► **Measurements of temperature**
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Correction of the initial temperature in the tanks, regarding to the **equilibrium**

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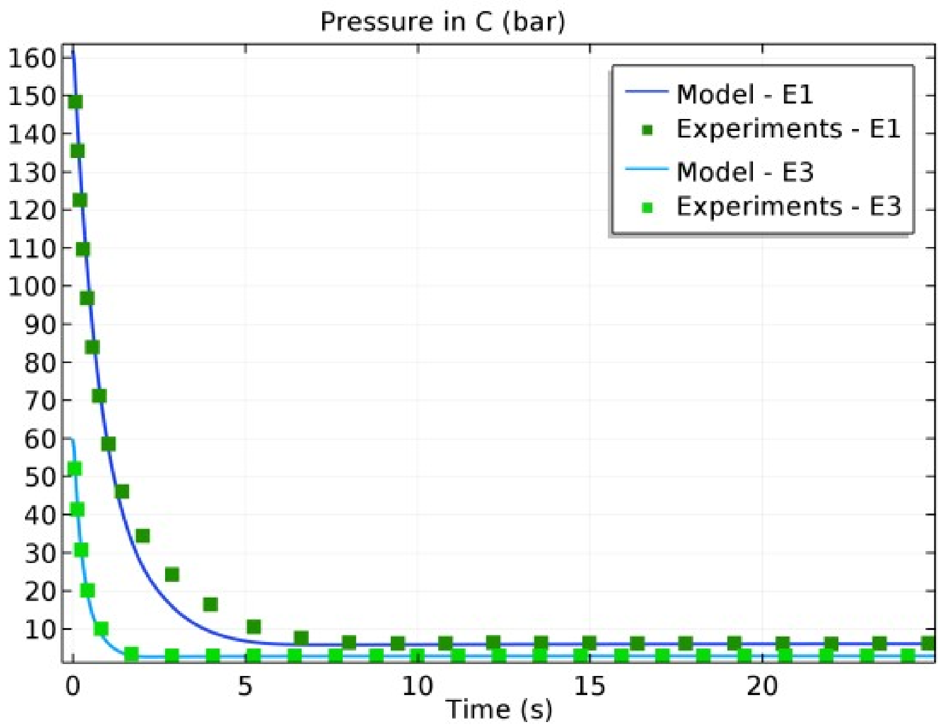

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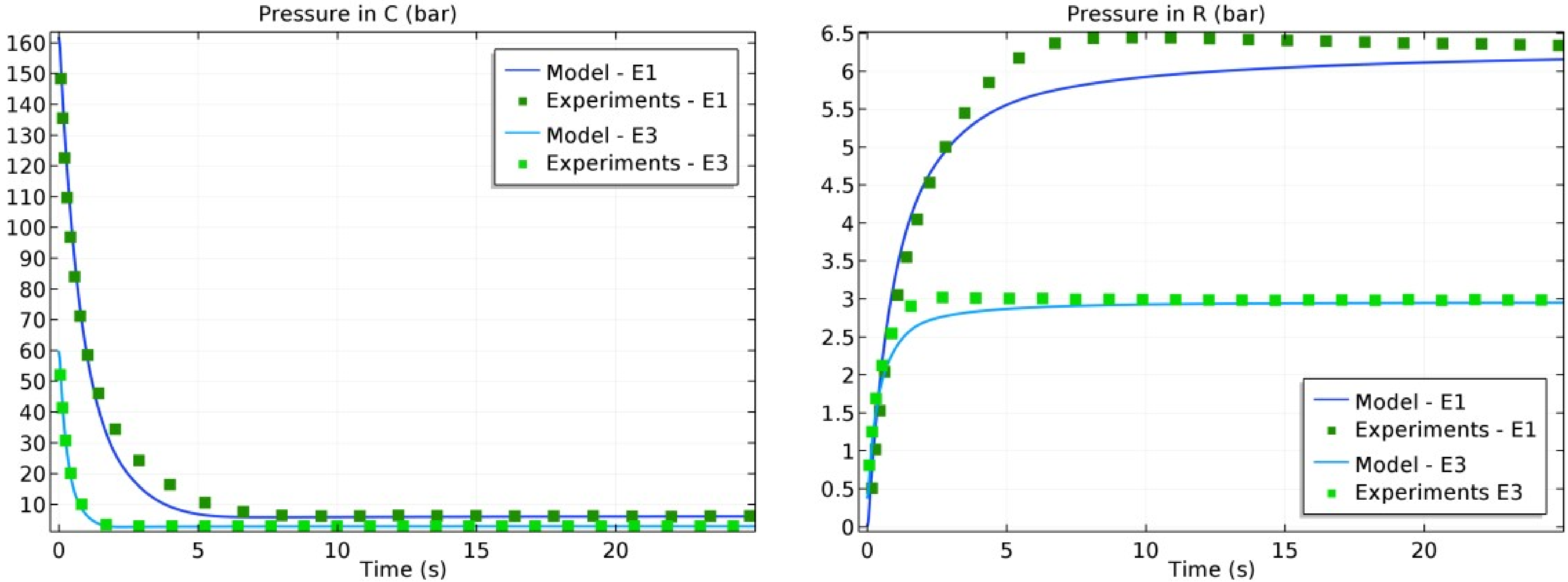

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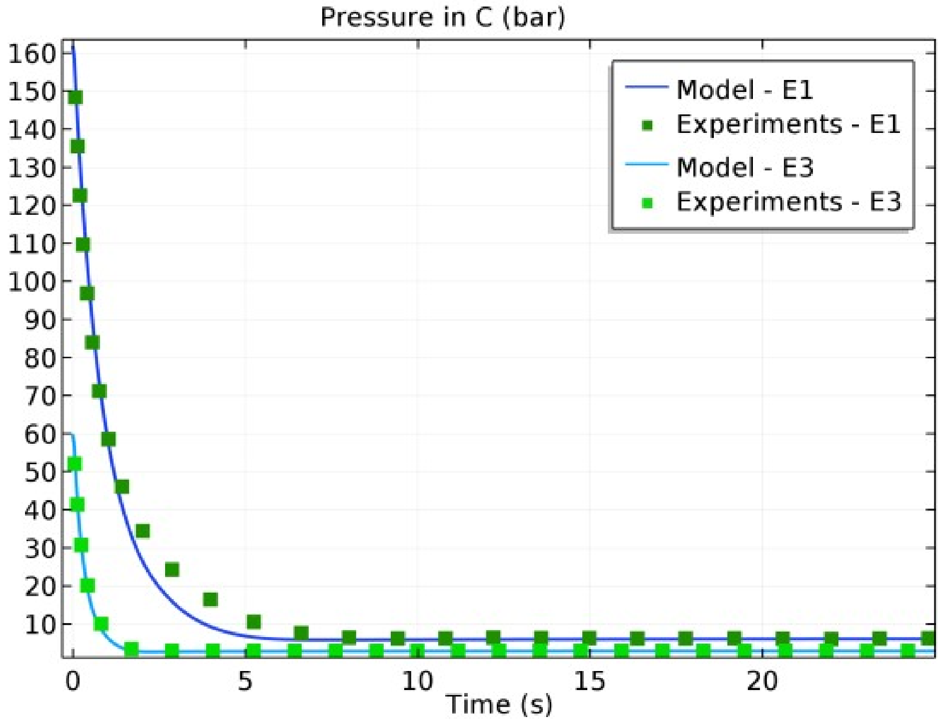

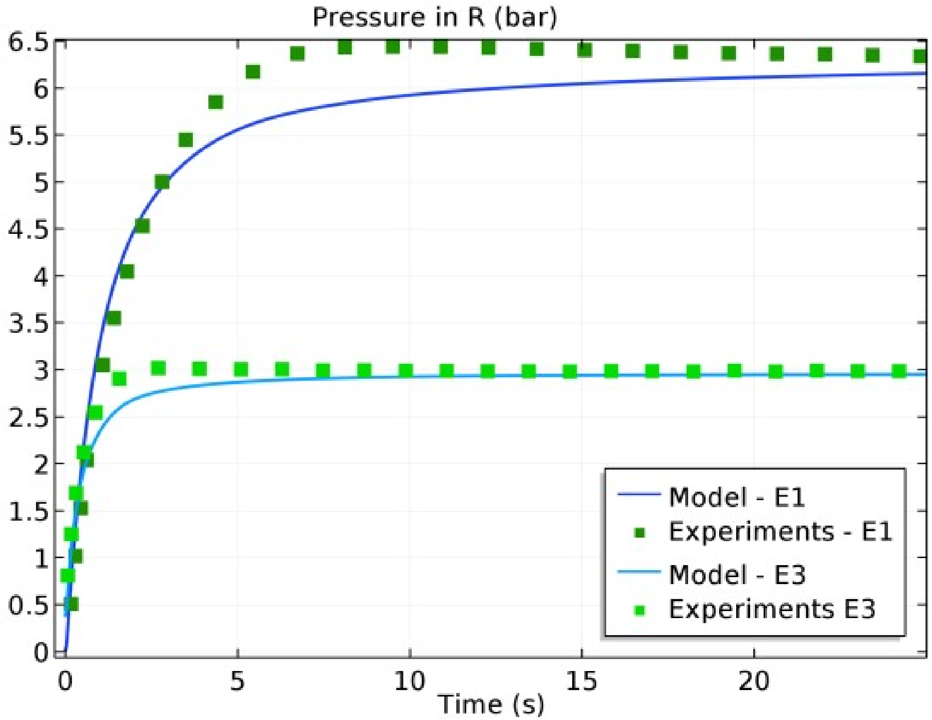

The results of the model fits to the experiments in pressure!

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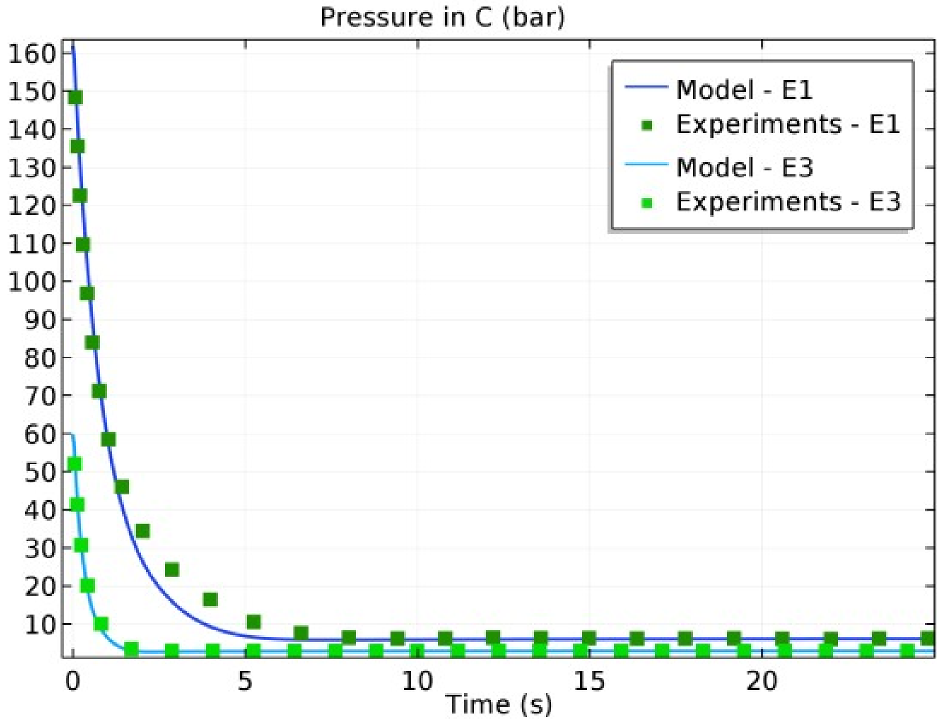

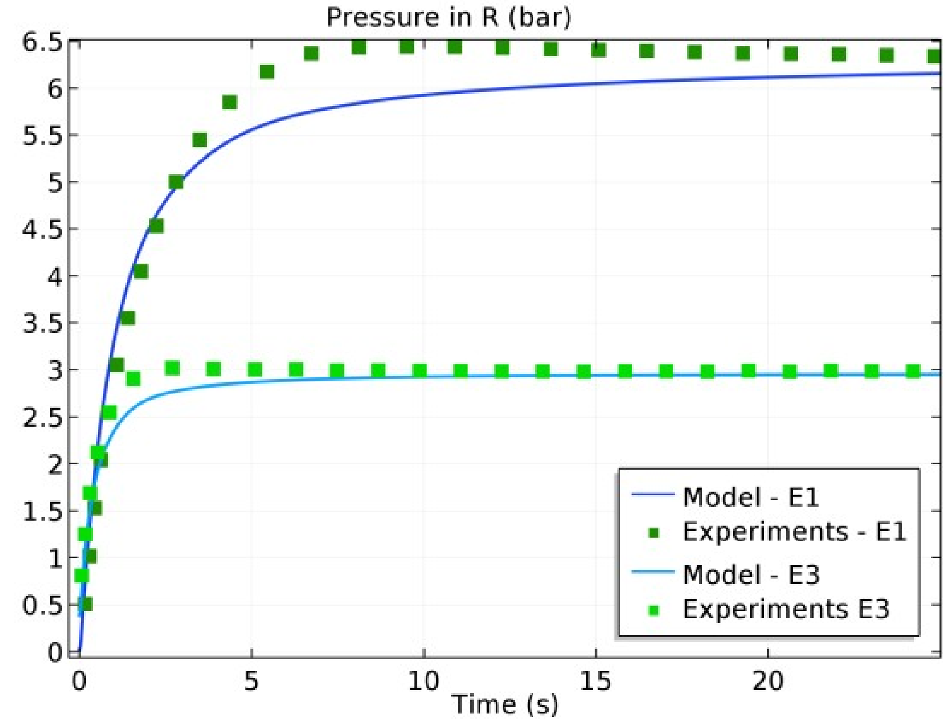

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Use of the model to detect experimental flaws

Conclusions

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General enough interfaces to implement it

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The degree of **accuracy** is satisfaying